Renewable and Sustainable Energy Reviews 41 (2015) 368–378

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Possibilities and challenges of China's forestry biomass resource utilization

Zhongfu Tan, Kangting Chen, Pingkuo Liu *

School of Economics and Management, North China Electric Power University, Beijing 102206, China

ARTICLE INFO

Article history:
Received 15 May 2014
Received in revised form
24 July 2014
Accepted 6 August 2014

Keywords:
Forestry biomass resources
Possibilities
Challenges

ABSTRACT

Forestry biomass resource has many advantages, which makes it a significant new energy to substitute fossil energy as an important role of biomass resources. For the utilization of China's forestry biomass resources, this paper analyzed the possibilities of its development from the aspect of policy, resource endowment, market and technology, and discussed its development challenges from the aspect of policy, economy, society, technology and resource endowment. Forestry biomass resources are very abundant in China. It has made a significant breakthrough in forest biomass resource utilization, with great prospects. Although there are still some difficulties and challenges in the policy, resource endowment and other aspects, these challenges are not insurmountable. Therefore, forestry biomass resources should develop in a way with Chinese characteristics considering the national condition.

Contents

1. Introduction . . . 369
   1.1. Background . . . 369
   1.2. Literature reviews . . . 369
2. Status quo . . . 370
   2.1. Resource supply . . . 370
      2.1.1. Residues from forest growth . . . 370
      2.1.2. Residues from forestry production . . . 371
      2.1.3. Energy forest . . . 371
      2.1.4. Algae . . . 371
      2.1.5. Industry status . . . 372
   2.2. Resource demand . . . 372
      2.2.1. Fuel ethanol . . . 372
      2.2.2. Biodiesel . . . 372
      2.2.3. Biomass power generation . . . 372
      2.2.4. Biogas . . . 373
   2.3. Market price . . . 373
      2.3.1. Fuel ethanol . . . 373
      2.3.2. Biodiesel . . . 373
      2.3.3. Biomass power generation . . . 373
      2.3.4. Biogas . . . 373
   2.4. Environmental system . . . 373
3. Possibilities of utilization . . . 374
   3.1. Policy support . . . 374
   3.2. Resource endowments . . . 374
   3.3. Market environment . . . 375
      3.3.1. Current competitors . . . 375

* Corresponding author. Tel.: +86 10 1963118, +86 130 1116 8395.
E-mail address: pingoforever@sina.com (P. Liu).

http://dx.doi.org/10.1016/j.rser.2014.08.059
1364-0321/

3.3.2. Potential competitors. . . . 375
3.3.3. Bargaining power of customers. . . . 375
3.3.4. Bargaining power of suppliers 375
3.3.5. Threats from substitutes 375
3.4. Technology 375
3.4.1. Development and utilization of forestry biofuels 375
3.4.2. Research technology of forestry biodiesel 376
3.4.3. Development technology of forestry bioethanol 376
3.4.4. Development and utilization of forestry biomass power 376
4. Challenges of utilization 376
4.1. Political aspect 376
4.2. Economical aspect 376
4.3. Social aspect. . . . 377
4.4. Technological aspect 377
4.5. Resource aspect 377
5. Conclusions and prospects 377
5.1. Conclusions 377
5.2. Prospects 378
Acknowledgments 378
References 378

1. Introduction

1.1. Background

Forestry bioenergy has become the most promising substitute for oil because of its advantages such as cleanness, abundance and environmental protection. Facing an increasingly severe energy crisis, countries all over the world have considered efficient utilization of forestry biomass resources as an important factor, when they adjust their strategies of energy development [1].

In the United States, forest fires caught the attention of their people in 2008. It was also becoming increasingly important to reduce the risk of forest fires. This fact inspired the enthusiasm of people to take part in forest thinning projects and forestry biomass resource utilization for energy production. The potential of forestry biomass in the western United States was estimated at 2230 MW (2008). If the development of 30 GM clean and diversified energy in 2015 is taken into account, half of China's energy will come from forestry biomass. To develop forestry bioenergy successfully and to recover investments in fixed assets continuously, biomass removal and collection should have a long-term preparation over at least 20 years [2]. In addition, European countries are also to increase the utilization of forestry biomass resources. In 2012, for example, the used volume of wood chips in Finland increased by 8 times of the volume in 2000, with more than 7.5 million cubic meters of biogas energy provided for the nation [3].

China is a large energy producer as well as a big energy consumer, so it is difficult to achieve the sustainable development of economy, society and environment simply relying on fossil energy. Although the per capita arable land area is relatively small in China, the amount is huge. In addition, a number of existing starch plants and fiber plants are also excellent sources of forestry bioenergy. There are large amounts of algae in the forest. As one kind of biofuel raw material, the advantages of algae have been recognized. According to the estimation in 2011 [3], a hectare of corn only can produce 18 gal of biodiesel per year and a hectare of palm trees only can produce 700–800 gal, while a hectare of algae can produce 20,000 gal. In addition, the special carbon structure in different kinds of algae can allow for "designing and developing diesel", which can meet a variety of special purposes. After the algae oil is extracted, the residue can be used for the production of cellulosic ethanol or animal feed.

Therefore, to promote the development and utilization of forestry biomass resources, China has already started research studies, development and process of forestry biomass resources. An industrial chain for the production and processing of major forestry biomass resources has been initially established. The government has also made a great contribution to solving forestry bioenergy bottlenecks and promoting the development of China's forestry energy industry [4].

1.2. Literature reviews

After the 1950s, the outbreak of the oil crisis had a huge impact on the global economy, and the energy crisis seemed to be inevitable. With respect to renewable energy, biomass energy is very similar to fossil energy in chemical composition and energy utilization, and thus it has the largest potential to substitute for conventional energy [5]. In 2004, International Conference on Renewable Energy in Bonn, Germany stressed that biomass energy would be one of the most promising energies in the future [6]. Converting forestry biomass to liquid fuels is becoming the focus of research for scientists all over the world. The UK and the US, for example, are carrying out research and application of the "oil plant" [7]. Many countries have developed some programs for biomass energy research and development, such as Japan's sunshine project, India's green energy engineering, America's energy farm, Brazil's ethanol energy plan, etc. [8]. In addition, some European countries, such as Austria and Sweden, pay attention to the utilization of biomass heating, so far the ratio of biomass heating has reached 25% [9].

The research and practice in other countries on bioenergy is relatively more; the main objectives of the study include: the links among various factors influencing biomass production, the methods to make the right decisions and policies for the development of bioenergy, and the policy effects on the development of biomass energy industry [10]. For the development of forestry biomass resource that started earlier in the foreign countries especially in Nordic countries, many theories and practices are worth learning [11]. Nevertheless, when the application converts into the large-scale utilization and development of forestry biomass resources in the world, some scientists still question the development of forestry biomass resources [12].

China has a vast territory and a widespread distribution of forests, and contains a large number of biomass resources [13]. However, there are few studies on China's forestry biomass resources. This means the development and utilization of forestry

biomass resources not only have distinctive features and advantages in forest construction, but also conform to the trend of international bioeconomic development [14]. Developing alternative energy sources and improving China's energy structure are not only the need of low carbon development, but also the assurance for necessary future energy supply; thus the development of forestry biomass resources has great prospects [15].

At present, Chinese provinces are actively studying the development and utilization of forestry biomass resources. For Hubei Province, the excessive dependence on imported energy and the coal-dominated energy consumption structure not only restrict the local economic development, but also cause environmental pollution, so it makes Hubei Province pay more attention to the development and utilization of bioenergy [16]. Through increasing efforts of researching, development and cooperating with the National Academy of Forestry, Henan Province has achieved some success in the research and development of forestry biomass resources [17]. Jilin Province has abundant forestry resources, so it has potential advantages of using forestry biomass resources. The local government proposed a construction and utilization strategy of "*two zones and two sections in three steps*" for forestry biomass resources [18]. In Heilongjiang Province, there is a greater proportion of coal industry. The ecological environment is facing a huge pressure, and forestry resources have not been rationally used. So the local government is increasing the development and utilization of forestry biomass resources, and is giving full play to the ecological benefits [19]. In addition, the Inner Mongolia region of China is also actively developing forestry biomass resources and has conducted researches related to bioenergy species in the region, which provides strong support for the construction of forestry bioenergy [20].

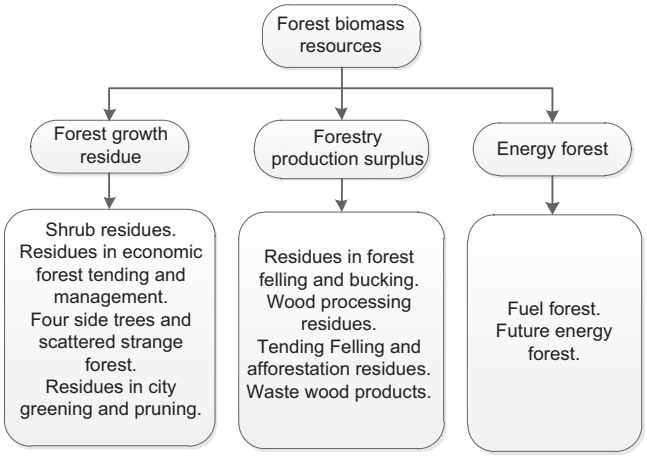

Fig. 1. China's forestry biomass resources.

Chinese scholars believe that the active utilization of forestry biomass resources can effectively reduce greenhouse gas emissions and improve the ecological environment [21]. There was a good momentum of forestry biomass energy industry in China, but China's forestry biomass industry started late. On the whole, the level of industrialization and commercialization is relatively low, and sustainable development is lacking. So compared with some advanced countries, China still needs to address some gaps [22].

2. Status quo

Forestry biomass resources include biological accumulation, bark, leaves and oil tree fruits (seeds) on the ground and under the ground. The utilization of forestry biomass resources is called forestry bioenergy, which is transferred by the biomass stored in forest. Forestry bioenergy mainly refers to the energy that is formed by the direct combustion or modern transformation techniques, and could be used for power generation and/or heating [23].

2.1. Resource supply

At present, China's forestry biomass resources mainly arise from forestry waste during forest growth, forest production and operation process, as well as during combustion of firewood. The classification of China's forestry biomass resources is shown in Fig. 1.

2.1.1. Residues from forest growth

(1) *Shrub residues*. In 2013, the area of shrubbery, accounting for 17.66% of the total area of the national forest, was 53.5 million hm^2 in China. According to the existing research results [24,25,5], the biomass production volume of China's shrubbery was 2–8 t/hm^2; if it is calculated for 6 t/ha, the existing biomass volume of shrubbery was approximately 320 million tons. Fig. 2 shows the scale of various types of forest area.

(2) *Residues from economic forest tending and management*. Economic forest refers to the forest whose main objectives are to provide the forest products but wood, such as fruit, bark, branches, leaves, buds, shoots, sap, resin, etc. It is also called special economic forest. In 2013, there was 21.43 million hm^2 of economic forest in China. When replacing or pruning the economic forest annually, for example, it could produce the branches and other waste of about 1 ton/hm^2. The total amount of pruning branches in national economic forest is about 21.43 million tons every year.

(3) *Four-side trees, open forest and scattered trees*. Four-side trees refer to the trees in the village-side, house-side, road-side and river-side. In 2013, there was about 1.112 billion cubic meters of Four-side trees, open forest and scattered trees in China, the

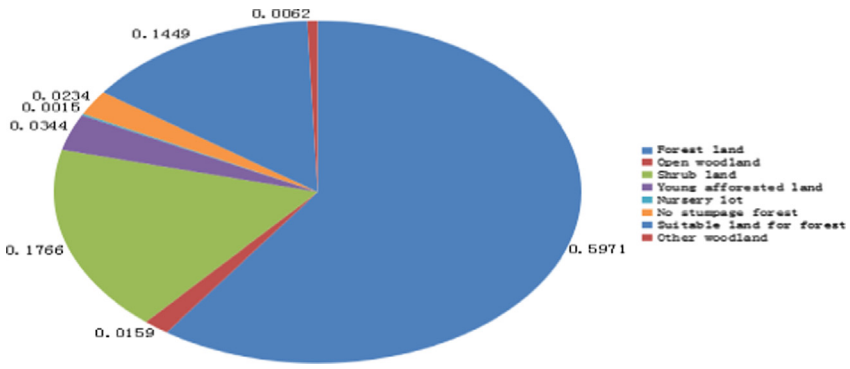

Fig. 2. Scale drawing of various types of forest areas.

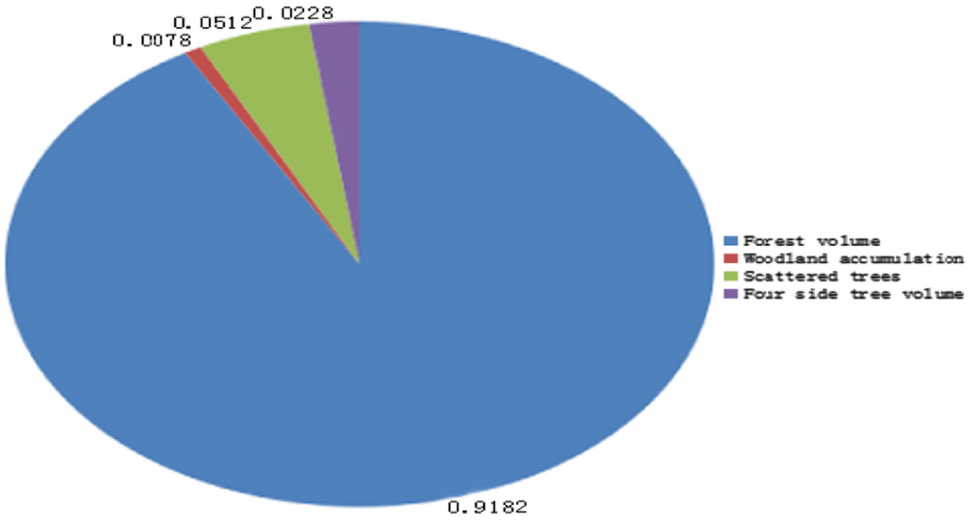

Fig. 3. Scale drawing of various types of forest reserves.

area accounted for about 7.4% of the forest reserves. The scale of various types of forest reserves is shown in Fig. 3.

(4) *Residues from city greening and pruning*. By 2013, the forest area for greening of city and landscape trees in China could be converted into 4 million hm^2, forestry biomass resources reached 600–700 million tons, and the wastes produced by tree pruning and tree replacing were up to 40 million tons.

2.1.2. Residues from forestry production

(1) *Residues from lumbering*. Residues from forest harvesting refer to branches, fallen dead wood, injured trees, abandoned trees, etc. They are left on the ground after felling. In 2013, the area of mature forest and overripe forest was about 28.74 million hm^2, and the volume was about 5.52 billion m^3. However, due to harvesting conditions, protection requirements, homeland security, and many other restrictions, timber cannot be fully harvested. According to the "*forest cutting quota*" approved by the State Council during the "Twelfth-five-year plan" period (2011–2015), the annual cutting quota should be 270 million m^3.

(2) *Residues from wood processing*. The wood processing residues are mainly from the commercial timber forest in China. In the wood processing factory, wood produces residues such as bark, skin and so on from the beginning of the processing to the processed wood products. After processing, 15–34% of one log becomes waste material. Among them, planks, slab and wood shavings account for 71% of the residues, while sawdust accounts for about 29%.

(3) *Residues from tending felling and afforestation*. In 2013, there was 56.0 million hm^2 of young forest area and 53.84 million hm^2 of middle-aged forest in China. The young forest area accounted for 66.75% of the total forest area, and it was a major component of the forest.

(4) *Wasted wood products*. Wasted wood products refer to all kinds of wooden furniture, doors, windows, pillars of wood, sleepers and other kinds of obsolete wood products. There are as much as 20 million m^3 (about 80 million tons) wasted wood products each year in China, due to renovation of dilapidated buildings and furniture update and elimination [24].

2.1.3. Energy forest

(1) *Fuel forest*. The development of China's fuel forest has begun to take shape. In 2013, the area of fuel forest was about 1.7 million hm^2, which is 0.96% of the total forest. The volume of fuel forest was about 39 million m^3, which is 0.29% of the total forest volume. According to the calculation of the area, volume and species composition of provincial fuel forest, the total biomass resources were about 38 million tons. Fig. 4 displays the composition diagram of forest land.

(2) *Future energy forest*. If the afforestation of energy forest happens once, the forest can be developed and used for years. It facilitates the implementation of intensive management, and it is the main development direction of future supply of forestry biomass resources. The forestry biomass resources from energy forests mainly depend on the amount of land available for energy resources and the amount of output per unit area of forest [26].

2.1.4. Algae

The forest area with a variety of algae is broad in China. As important renewable resources, algae have lots of features, such as wide distribution, high photosynthesis efficiency, strong environmental adaptability, short growth period and high yield. Further development and utilization of algae, especially microalgae, will provide new hope for China.

At present, Chinese researchers and the government have been gradually realizing that algae have many aspects of developing values; moreover, they need sunshine, water and CO_2 rather than nutrients, so the algae will not contend with cash crops for the ground. Compared to other plants, algae contain high lipids, polysaccharides and so on, so they can be used to produce biodiesel and ethanol, and they are also expected to become a new way of producing hydrogen. Compared with lignocellulosic materials, the photosynthesis efficiency of algae is higher than trees. In addition, algae are easy to crush and dry, so they have low pretreatment costs. Additionally, the biomass fuel calorific value from algae is up to an average of 33 MJ/kg, which is 1.6 times that of wood or straw. Last of all, the growth and reproduction of algae mainly rely on photosynthesis; they can capture CO_2 in emissions to protect the environment.

Therefore, the algae in forest, as a source of energy crop, are mainly developed to produce ethanol, biodiesel, fuel oil or hydrogen.

2.1.4.1. Fuel ethanol production. Algae have high growth rates and high biomass characters. They can also produce ethanol with high

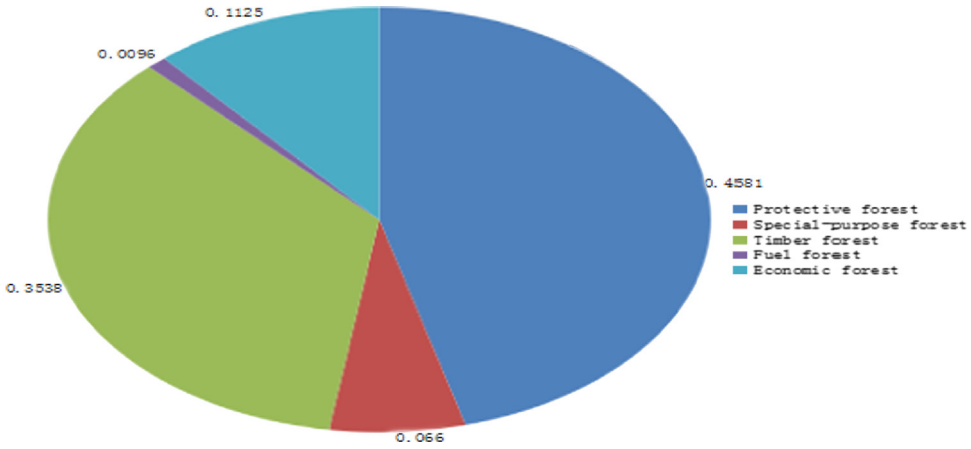

Fig. 4. Composition diagram of forest land.

Table 1
Yield, hydrolysable carbohydrate and potential bioethanol production in the major terrestrial crops and algae.

Energy plants	Average yield [kg/(hm^2 year)]	Dry weight of water-soluble carbohydrate [kg/(hm^2 year)]	Theoretical yield of fuel ethanol [kg/(hm^2 year)]
Wheat	2800	1560	1010
Core	4815	3100	2010
Beet	47070	8825	5150
Sugarcane	68,260	11,600	6756
Alga	730,000	40,150	23,400

production. According to estimation [3], 1 hm^2 of cultivated algae can produce fuel ethanol of 8.4 t. The production efficiencies among the main land plants and the algae are compared as shown in Table 1. From that, it is not difficult to know that the annual production of ethanol by algae is much higher than any terrestrial crops.

In addition, the production costs of algae in fertilizer, artificial and machinery are lower than terrestrial energy crops. For example, the total cost of ethanol production by algae is about $ 320–380 per ton in China in 2013 (including planting cost), but it needs $500–550 when using corn.

2.1.4.2. Biodiesel production. Oil content in some algae is up to 50%, which can be converted into biodiesel or aviation fuel. According to the study in 2010 [5], 1 ha of soybean can produce 17 GJ biodiesel fuel per year, 1 ha of rapeseed can produce 46 GJ, 1 ha of oil palm can produce 230 GJ, while 1 ha of algae can produce 684 GJ biodiesel fuel per year; thus the biodiesel production of algae is 3–40 times of these crops. However, the greatest difficulty is how to reduce the production cost. It is estimated that the production cost of 1 gal extract oil from algae is more than $3.2 [13].

2.1.5. Industry status

Forestry biomass industry has the characteristics of large-scale investment and long cycle of biotechnology research and development. At present, the suppliers of China's forestry biomass resource are few, and most of the suppliers are state-owned enterprises (expect for the regional forestry bureau), such as *CNPC* (Market value of $ 23.727 billion), *CNOOC* (Market value of $ 725.29 billion), *Sinopec* (Market value of $ 303.17 billion)[1], *COFCO*, *Inner Mongolia Forestry Group*, *Jilin Forestry Group*, *Greater Khingan Range Forestry Company* and so on. Among them, the *CNPC* will be able to realize more than 60,000 t of biodiesel raw materials supply per year, and the *CNOOC* can realize about 30,000 t of bio-liquid fuel raw materials supply annually.

[1] Market value in April of 2014.

2.2. Resource demand

The applications of forestry biomass resources are mainly fuel ethanol, biodiesel, biogas and biomass power generation in China.

2.2.1. Fuel ethanol

In the context of China's "*deepening dependence on oil imports*" and high international oil prices in the coming years, the domestic demand for fuel ethanol is increasing. It is expected that fuel ethanol demand in China will reach 5 million tons in 2018. So, China is developing the forestry biomass resources to produce fuel ethanol [27]. Fig. 5 shows the demand of fuel ethanol market in China from 2012 to 2016.

2.2.2. Biodiesel

China is the second largest oil consumer country in the world, and the external dependency of oil is close to 50% [4]. The diesel demand was about 100 million tons in 2010, and it will reach 130 million tons in 2015. In addition, the air pollution of China tends to deteriorate, so environmental protection and biofuels development have become the strategic needs of China. In the production of biodiesel, China is actively developing the use of forest biomass resources, such as the use of woody oil plants [28].

2.2.3. Biomass power generation

The development of biomass power generation and the implementation of substitution for coal can significantly reduce carbon dioxide and sulfur dioxide emissions with huge environmental benefits. According to the prediction from U.S. Department of Energy (2012), the biomass power generation will occupy the dominant position in renewable energy by 2025. "*China's long term development plan of renewable energy*" has proposed that the capacity of biomass power generation would reach 30 million kW by 2020. Chinese government also encourages the non-food biomass fuel production technologies, such as biomass cellulosic ethanol, biodiesel and so on. For the above-mentioned reasons, the demand of forestry biomass resources is increasing [29]. The changing trend of total installed capacity of biomass power generation is shown in Fig. 6.

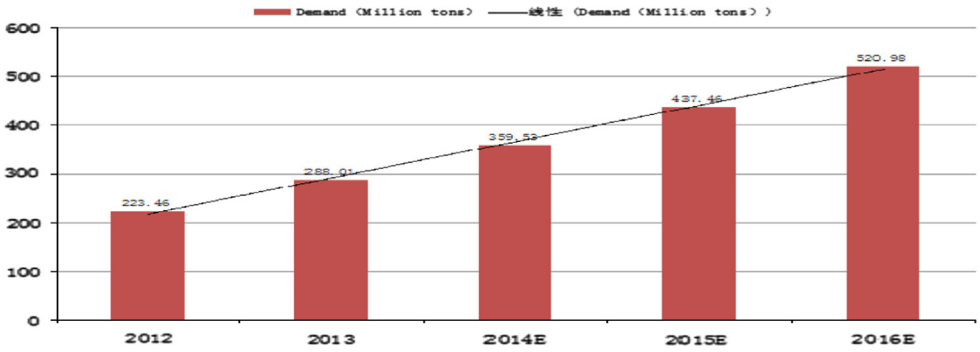

Fig. 5. Demand-expected of fuel ethanol market in China from 2012 to 2016.

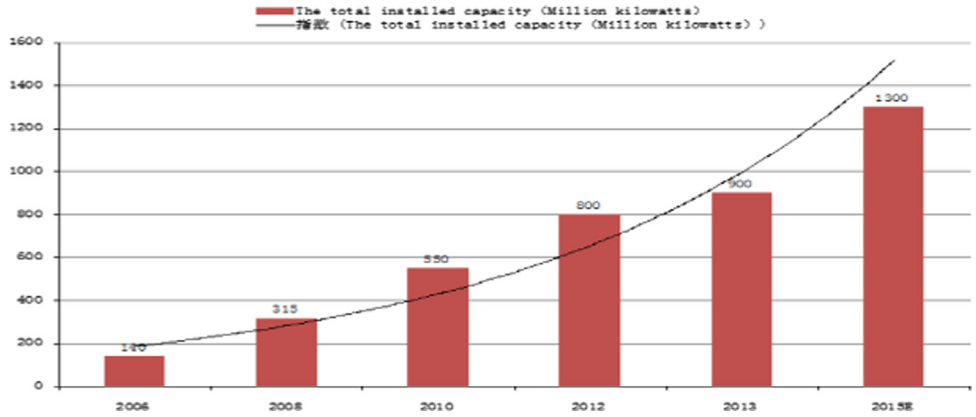

Fig. 6. Variation of total installed capacity of biomass power generation from 2006 to 2015.

2.2.4. Biogas

Biogas technology can integrate energy, planting and breeding actively. It is important to solve the problems of rural living, energy production, ecological balance & protection and environmental health. As the end of 2010, there were 73,000 large and small biogas projects, including 200 extra-large projects, 4963 large-scale projects and 22,700 medium-scale projects. It is estimated that the increase of new energy converted into standard coal can reach millions of tons every year, which will be able to undoubtedly increase the demand for its raw materials [19].

2.3. Market price

2.3.1. Fuel ethanol

At present, the price of domestic fuel ethanol is implemented by government pricing. The fuel ethanol price is equal to the ex-factory price of gasoline 90# (for army and national reserves) multiplied by the reduced coefficient of 0.911 (coming from the vehicle ethanol gasoline deployment cost of sales price), and the ex-factory price of gasoline 90# is announced by the National Development and Reform Commission in the same period. This fuel ethanol price is a settlement price for fuel ethanol production enterprises, petroleum enterprises and petrochemical enterprises. In 2010, fuel ethanol price[2] was about $1029.7 per ton in China, and it was about $1287.2 in 2013 [30].

2.3.2. Biodiesel

The 70–80% of processing cost of biodiesel is for the raw materials. The main raw material of biodiesel is the woody oil in forestry biomass resources. Taking the tung oil in woody oil as an example, the price was $965.4–$1110.2 per ton in 2013, according to which the total cost of biodiesel was $1235.1–$1392.9 per ton. This production cost is close to petroleum diesel fuel cost [31].

2.3.3. Biomass power generation

Compared with coal power plants, the proportion of fuel costs in biomass power generation is higher. At the initial stage of biomass power generation development (2006), fuel price was about $32.2 per ton. Fuel costs accounted for about half of the total generation cost, and fuel price has risen to $56.3 per ton by 2013. At the same time, the price of forestry waste, such as fuel-wood, has been more than $48.2 per ton, fuel costs accounted for about 70% of the total cost of power generation [32].

2.3.4. Biogas

Compared with direct combustion, the investment in using forestry biomass for biogas fermentation is lower, and the energy-use efficiency of biogas is improved by 0.2–0.9 times of that of direct combustion. Per ton of straw could produce 1500 m^2 biogas (750 kg of standard coal equivalent) and generate 1875 kWh of electricity in China [33]. The price of biogas was $0.5/$m^3$ in 2013, while the investment in small biogas plants just required $65/kW in the same year.

2.4. Environmental system

The exchange of material between forest and air is mainly the exchange of CO_2 and O_2. Properly speaking, the forest will be able to fix and reduce CO_2 and increase O_2 in the atmosphere at the same time. This exchange plays an irreplaceable role in

[2] Exchange rate $1=6.2133RMB.

Table 2
Policies about forest biomass resources in China.

Year	Policy	Main content
2007	"*Bio-energy and Bio-chemical Raw Material Base Grant Funds Interim Measures*"	Subsidies standard of forestry raw materials base is $32.2 per mu.
	"*National Energy Forestry Plan*"	
	"'*Eleventh Five Year (2006–2010)*' *Construction Plan of Forestry Bio Diesel Raw Material Forest Base*"	The large-scale cultivation of energy forest is included in forestry development planning.
2008	"*Straw Energy Utilization Assistance Fund Management Interim Measures*"	The central government provides comprehensive assistance to enterprises of selling straw energy products.
2011	"*The National Forestry Biomass Energy Development Plan (2011–2020)*"	By 2015, the oil forest, wood energy forest and starch energy forest should be built for 8.38 million ha, volume of forestry biomass utilization should be more than 10 million tons of standard coal; at the same time, a batch of industrialization demonstration base would be built, and the volume of forestry biomass utilization would be more than 20 million tons of standard coal by 2020 [33, 5].
2012	"*China's Energy Policy*"	Forestry biomass power generation should be developed in the forest resource-rich region.
	"*Twelfth Five Year Plan (2011–2015) of Biomass Energy Development*"	It describes the development guidelines, objectives and key construction tasks of China's biomass development.

maintaining the balance between CO_2 and O_2, which is also important to reduce greenhouse effect and provide survival foundation. Calculations show that the total volume of carbon sequestration is 777.6 t per year and oxygen release is 2095.2 t per year in China in 2013, so the economic values that forest ecosystem created from carbon fixation and oxygen release of each year are $125,398.8 and $124,869.6, respectively.

Table 3
Comparison of forest resources inventory results between 2008 and 2013.

National Forest Resources Inventory (year)	2008	2013
Forest area (million hectares)	195	208
Forest reserves (million cubic meters)	13,721	15,137
Natural forest area (million hectares)	119.69	121.84
Plantation area (million hectares)	61.69	69.33

3. Possibilities of utilization

3.1. Policy support

In recent years, Chinese government attaches great importance to the exploitation and utilization of bioenergy, and has promulgated the "*Renewable Energy Law*". The Law has established a framework for incentives of developing renewable energy, including the special fiscal fund, national fiscal interest discount loans, tax concessions and so on. The related policies are shown in Table 2.

At present, the State Forestry Administration and the State Grid Corporation have signed an agreement, in which they are cooperating in the development of biomass energy and accelerating the integration of the forestry and electricity industry. Energy forest will be constructed in large scales in ecologically fragile, underdeveloped agricultural area, so it can play a role in ecological restoration, and in the development of biomass energy and promotion of rural economy. The State Forestry Administration has treated the forestry biomass energy development as an important content of the construction of modern energy [34].

In addition, the "Twelfth Five Year Plan" (2011–2015) has a great effect on the bioenergy industry. It not only puts forward the problems of China's biomass energy development, such as poor accuracy of resource investigation and evaluation, big difficulty of collecting materials, low level of technology and high degree of industrialization, but also determines the key tasks of development. The key tasks are accelerating the large-scale development and utilization of biomass, promoting the comprehensive utilization and industrialization demonstration of bioenergy, organizing the promotion and utilization of bioenergy, and strengthening the construction of bioenergy technology, equipment and industrial system [35].

Forestry biomass energy development is in a favorable growth opportunity and cooperation with the rest of the world, and it is in a good environment for government attention, sector support and industry participation in China. This provides an opportunity for the development of forestry bioenergy development in China. In addition, the related laws and regulations of energy and environment that Chinese government promulgated and implemented recently also encourage the development of environment-friendly energy industry.

3.2. Resource endowments

The development of forestry bioenergy is an important measure to optimize the energy structure and guarantee energy security. China's mineral energy is relatively poor, so the development of forestry biomass resources has a huge resource advantage.

According to the inventory results of forestry biomass resources in China during 2008–2013, the national forest area was 208 million ha, forest coverage rate was 21.63%, and forest stock volume was 15.137 billion m^3. Artificial forest area was 69 million ha, and the volume was 2.483 billion m^3 [36]. Compared with the inventory results during 2003–2008, the main differences are shown in Table 3.

It has a large amount of forest biomass resources in China, so it can be seen that the development prospect of China's forestry biomass resources is very broad. The resource has properties of abundant species, strong regeneration and high combustion value. And the cultivation of forestry biomass resources also has great potential. These are the basis and the strengths for developing forestry biomass resources.

China has a large population and small land, by which it is decided that China should develop bioenergy positively on the premise of food security. *First of all*, the forestry biomass resources come from woodlands that can be exploited, which means that the protected land is excluded. *Secondly*, forestry biomass resource utilization will not pose a threat to the supply of industrial wood and traditional fuel-wood, and will not cause excessive logging of forests. *Finally*, the cultivation of forestry biomass resources mainly needs marginal land, such as barren hills, wasteland, the sandy land that is unsuitable for food crops and saline alkali land, so it needn't occupy farmland. Therefore, forestry biomass

resource has a unique advantage for the development and utilization of bioenergy [37].

3.3. Market environment

With respect to the forestry biomass resources market, a Potter's Five Forces model [38] is used to analyze (Fig. 7).

3.3.1. Current competitors

For forestry biomass resource, its direct competitor mainly is the agricultural biomass resource. Forest area is about 1.42 times the area of cultivated land in China, and the amount of forest resources is slightly higher than the crops per hectare in China, so the amount of energy savings in forestry is much larger than the agricultural one. In addition, the harvesting of forestry biomass resources is not seasonal, while the warehousing cost is low, and the purchase price is basically stable, all of which are beneficial for industrialization of biomass energy. So increment operation and investment cost of forestry biomass energy is much lower than the agricultural energy [39].

3.3.2. Potential competitors

Potential competitors of forestry biomass resources are other forms of biomass resources, such as domestic sewage and industrial organic wastewater, city solid waste and animal manure. Compared with sewage, municipal waste, etc., the utilization of forestry biomass resources is more systematic and perfect, the technology is more mature, the resources are more abundant, and the development potential is greater, so the competition ability of potential competitors is not strong enough for forestry biomass resources.

3.3.3. Bargaining power of customers

The buyers of forestry biomass resources belong to a capital-intensive industry. This industry has a large scale of investment and long capital payback, so the investment is easy to deposit. The forestry biomass products do not have the price-competitive advantage compared with the products of conventional energy, which increases the investment risk. Therefore, bank loan is a problem, which daunts many small and medium-sized enterprises. For these reasons, the local bioenergy companies get the investment mostly from the government. While it prevents the copycat, market monopoly is formed [16]. So, the buyer has a strong bargaining power.

3.3.4. Bargaining power of suppliers

In the initial development stage of the industrial chain of forestry biomass resources, the industry is a typical labor-intensive industry from the raw materials cultivation, collection and transportation processes, so the bargaining power of suppliers is rather weak.

3.3.5. Threats from substitutes

The substitutes of forestry biomass resources are mainly coal, oil and other fossil fuels. China is a country where mineral energy is relatively poor and the dependence on imported energy is high. It can be expected that net imported oil will reach 215–217 million tons in 2020, and the dependence will reach 56–60% in that year. Energy security has become an important issue in policy, economy and diplomacy of China. Therefore, it is the main direction of energy development to vigorously develop renewable energy including forestry bioenergy in the future, and there is also an urgent need to solve the problem of energy security [40]. However, compared with mineral resources, the shortage of forestry biomass resources is that its advantages cannot be converted into market competitiveness and the abundant raw materials cannot produce the reasonably cost-effective energy products, so the forestry biomass resources are not market favorites, and forestry biomass energy enterprises are of little significance in the market.

To sum up, forestry biomass resource has some advantage and strong development potentials in the market, but its cost and price problems urgently need to be solved in the future.

3.4. Technology

Technology and equipment of forestry biomass resources utilization have been studied systematically in China. Some research results have achieved important breakthrough, so it provides technical support to accelerate the industrial development of forestry bioenergy.

At present, some technologies of China, such as energy resource species survey, breeding, intensive cultivation, solid fuel, gasification, biodiesel and ethanol fuels, have reached the international advanced level. China has also accumulated a number of key technologies with independent intellectual property rights, so it has fully achieved the requirements of mass productions (Fig. 8).

3.4.1. Development and utilization of forestry biofuels

China's key technology of exploitation and utilization of forestry biomass resources becomes more and more mature, and it has carried out a certain scale of industrialization demonstration. *On the one hand*, the Clean Energy Research Center of Tsinghua University and *Beijing Huizhong Company* have co-invented the "*cold compression molding technology*", which provides good development prospects for the processing and application of forestry biomass solid fuel. *On the other hand*, there are many research institutions now in China studying the economic and technological processes of producing liquid fuel under atmospheric pressure, so that they can achieve mass and commercial production of high-quality liquid fuels.

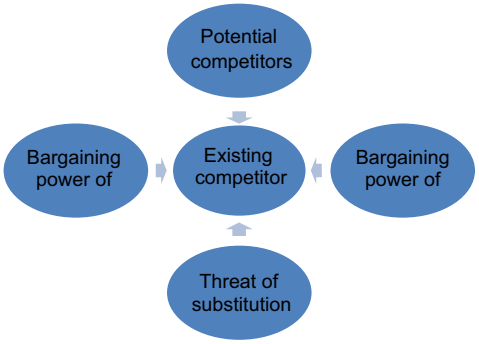

Fig. 7. Potter's Five Forces model.

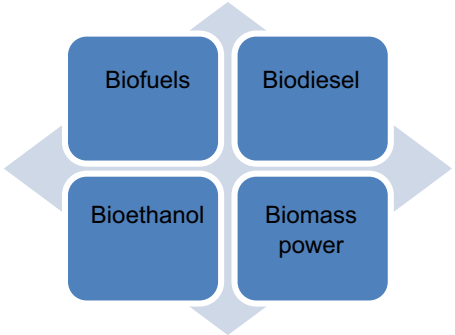

Fig. 8. Analysis of current technologies in China.

3.4.2. Research technology of forestry biodiesel

The development and utilization of forestry biodiesel already have a good foundation specifically in woody fuel conversion technology. The independent innovation of biodiesel technology has achieved industrialization development results in China. Chinese Academy of Forestry has established an integrated production line which has an annual output of 500 t biological diesel oil and chemical products.

3.4.3. Development technology of forestry bioethanol

Since the 1950s, China has carried out the study of biochemical acid hydrolysis and cellulose enzymatic hydrolysis. In recent years, China has been studying the key technique of using lignocellulose for fuel ethanol and other biochemical new technology systematically, and has started the research of molecular biology and gene engineering related to bioethanol.

3.4.4. Development and utilization of forestry biomass power

The technology of biomass power generation is relatively mature. Forestry biomass power generation is mainly based on forestry residues and biogas now in China. Some large domestic energy development enterprises are involved in the form of investment in raw material base construction, equipment research and construction of cogeneration power plants, and they are showing a rapid development momentum [34].

4. Challenges of utilization

The forestry bioenergy is a renewable energy, and it can cause less pollution to the outside world compared to coal, oil and other fossil fuels; hence many countries are committed to developing the bioenergy industry. However, the application of biomass resources in any aspect will still cause a certain environmental pollution and ecological destruction. For example, in the process of fuel ethanol production, it consumes a large amount of water resources and discharge wasted water at the same time, thus causing water pollution. In addition, because the use of forestry biomass resources in China is still in its initial stage, there are also many challenges.

4.1. Political aspect

To ensure the steady development of forestry biomass resources, the Chinese government has issued a series of laws and regulations, subsidies and tax preferential policies, so a good macro policy environment is gradually formed. This policy environment actively promotes the development and utilization of biomass resources, but they are still inadequate in the development of forestry biomass resources. The specifics are illustrated in Table 4.

4.2. Economical aspect

First, the project investment of forestry biomass resources development and utilization mainly relies on government grants and loans, so the channel of investment and financing is narrow. The frequent fluctuations of international crude oil prices and the high market risk of developing biomass resources affect the enthusiasm of domestic enterprises to exploit forestry biomass resources. Enterprises lack participation as the main body of industrial development, so it is difficult to form a sustainable mechanism in the development and utilization of forestry biomass resources.

Second, the diseconomy of forestry biomass feedstock is also a big problem. For example, although it has made important progress in forestry biomass power generation, it is still subjected to constraints of excessive investment and high operating costs. The technology research for small biomass gasification power generation is less. And there is little practical experience in the application, which makes the promotion difficult. Therefore, there are only 2 forest biomass power plants in 14 biomass power plants that have been built. The annual capacity of forest biomass power plants is 300 million kWh, which accounts for 10.5% of the total generating capacity.

As the energy density of forestry biomass feedstock is low, the harvest is difficult. And it has seasonal restrictions and poor adaptability, so the feedstock cost increases with the increase of project scale. The relevant calculation shows that, when the scale of biomass power generation project is increased from 1 MW to 20 MW, the collection range of the required forestry biomass feedstock changes from 2 km to 30 km [41]. So the costs of the raw material collection, storage, management and other aspects are doubled. Because raw material planting and supplying of forestry bioenergy is a huge systematic project, the risk in bioenergy is high and market development is difficult, so it has affected the enthusiasm of enterprises, and restricted the normal development of the industry. Generally speaking, the degree of the scale of forestry biomass development and utilization is low in China.

Despite the dramatically increasing level of forestry mechanization, forestry bioenergy industry is still a labor-intensive industry. With the rural labor transferring, the labor cost rising rapidly and the cost of forestry biomass feedstock acquisition remaining high, the advantages of raw materials resources cannot be converted to economic and competitive advantages of energy products [42].

In addition, the forestry bioenergy has a low price, some relevant policies pointed that the biomass power tariff standard was composed of desulfurized coal tariff of each province (city, district) and subsidy (the subsidy standard is $0.05/kWh). The cost of biomass power generation is much higher than the cost of thermal power, so the actual tax of biomass power is higher than the thermal power because the value-added tax cannot be deducted [43].

Table 4
Political barriers.

	Classification	
Barrier 1	Policies	(1) The lack of standards and regulations and incentives. For example, tax policies about forestry biomass power generation have not yet been implemented since the “Renewable energy law” was published. (2) The lack of incentive mechanism of supply. Forestry biomass energy industry is a high-risk industry, but the effect of incentive policies for overcoming market risk is not obvious. (3) The ignorance of need in policy orientation. The policy orientation only attaches importance to supply, so the market strength to support the adjustment of energy consumption structure is not developed and there is no stable market demand [42, 38].
Barrier 2	System	There are no specific rules to regulate the work of comprehensive utilization of forestry biomass resource, and there are no specific penalties for not using behavior that should be comprehensively used [43, 2].
Barrier 3	Regulation	There is no special mechanism to manage the development of forestry biomass resources industry and no specialized department to manage the implementation of relevant national standards and policies.

Table 5
Technological barriers.

	Classification	
Barrier 1	Biomass Power	The technology of forestry biomass power generation is simple and the level of technology is low. There is no complete technical system. Inadequate investment constraints the improvement of technical level.
Barrier 2	Fuel Ethanol	The processing technology of forestry biomass fuel ethanol still needs further development; the main constraints are the high costs of cellulosic feedstock pretreatment and cellulose degradation.
Barrier 3	Biodiesel	Because the core technology of production does not break through and industrial chain is limited, it causes a great waste of resources and influences the development progress of forestry biomass energy.

4.3. Social aspect

In terms of social aspect, the utilization of forestry biomass is usually underestimated. In rural areas, many farmers develop the habit of burning straw; however, the local governments pay no attention to the use of that biomass. They only attach importance to economic growth but not to environmental protection; the concept and knowledge gaps have severely restricted the level of biomass utilization. Therefore, China should strengthen propaganda and awareness of the importance of biomass energy utilization. By strengthening leadership and implementing the responsibilities, the public should be made fully aware of the economic, environmental and social wealth of resource utilization [25].

Additionally, the forestry biomass resources cannot be developed without the support of talented personnel. There is a lack of professional, technical, and specialized personnel in forestry biomass resources business, so that biomass resources development technology and management innovation are insufficient, and the technical equipment and management level are far behind those of developed countries [44].

4.4. Technological aspect

Technology is the key factor for developing biomass resources, and it is the basis of making the bioenergy out of the laboratory and putting it into commercial mass production. The existing conversion and processing technology are not mature for China, so the advantages of forestry bioenergy are not reflected in the current fossil oil prices. There are several issues in the development of forestry bioenergy, such as the low technology level of the equipment and the few substantive breakthroughs in some core technology (i.e. cellulose producing fuel ethanol, etc.). These issues cause the insufficient development of forestry bioenergy industry, and it is difficult to create economies of scale (Table 5).

4.5. Resource aspect

Chinese terrain is varied, and geographical area of the countryside is vast. Forestry biomass resources are distributed in different regions, and there are differences between the north and the south. The resource distribution is dispersed in time and space, so it requires multiple transactions. The majority of forestry biomass raw materials is mainly collected by human, but the cost of raw materials collection is increasing relatively under the background of rural labor force shifting to the city constantly.

The density and proportion of forestry biomass raw materials are low, while the transport damage and storage costs are relatively high. The difficulty in collection and the instable supply of raw materials distinguish biomass energy development from other renewable energy sources, which are un-ignorable factors restricting the development of forestry bioenergy industry [45].

Moreover, from the viewpoint of total supply and total demand in forestry biomass resources, the supply capacity of forestry biomass resources is restricted by ecological, technical and economic factors, which can be used for modern development of biomass resources. The current planting and cultivation of forest energy plants in China have not reached the scale for utilization yet. Areas suitable for the cultivation of forest biomass plants mainly are the saline alkali soil, sand, mine, oil reclaimed land, and barren hills wasteland. Productivity level in these places is relatively backward. Lands become the primary means to making a living for local farmers, so a large-scale planting not only has the natural geographic barriers, but also faces the farmers' life pressure, which is a big uncertainty [43].

5. Conclusions and prospects

5.1. Conclusions

In summary, we reached the following conclusions:

1. On the one hand, it can be seen from the market that China possesses a large quantity and supply of forestry biomass resources, which lays the foundation for the development and utilization of China's forestry biomass resources. On the other hand, the demand for forestry biomass resources in China is also increasing, which promotes the applications of forestry biomass resources. However, due to imperfect technologies for forestry biomass resources, the cost in using forestry biomass resources is relatively high, which does not allow Chinese enterprises to enjoy price advantages.
2. With respect to possibilities from the aspects of policy, resource endowment, market and technology, it is advantageous to develop forestry biomass resources in the future. China has introduced several policies to encourage the development of forestry biomass resources, and the government and scientific researchers attach importance to the development of forestry biomass application technology. In addition, China has abundant forestry biomass resources, with many types, large volume, strong regeneration and high combustion value, so it has big potential to explore, and there is no doubt that it has built a solid platform for the utilization of forestry biomass resources. Because of the large energy demand, the development of forestry biomass resources not only increases the energy supply of the rural areas which lack fossil fuel and centralized power grids, but also has an important effect on improving forestry development mode, increasing employment of rural labor force, and adjusting the rural industrial structure. Finally, in terms of technology, with continuous innovation, China will have a certain ability to develop forestry biomass resources.
3. As to the challenges of using forestry biomass resources in China from the five aspects of policy, economy, society, technology and resource endowment, there are some disadvantages. First, China has a lack of standards, regulations and incentive measures for forestry biomass energy development policies. This situation should be further improved so as to gradually form a good macroeconomic policy environment. Second, the sources of investment are poor, and the financing channel of China's forestry biomass resources industry is

narrow, so the market has a high risk, and the cost of raw materials is high, which has seriously impeded the development of forestry biomass resources. Third, in China, the concept of forestry biomass resources does not penetrate the public, people have a lack of knowledge about comprehensive utilization. Besides, the lack of skilled personnel in this area also challenges the utilization of resources. For the immature technology of conversion and processing and the high costs, the market-competitive advantage of the forestry biomass resources is affected. Finally, because the distribution of forestry biomass resources is dispersed, its collection cost is high, and the source of supply is instable, which has become a major challenge for making better use of the resources.

In summary, as one of the most promising energies in future, forestry bioenergy has broad prospects for development in China. Although there may be some challenges and bottlenecks on the future path of development, it is not insurmountable. The development of forestry biomass resources utilization started late. But since the 1980s, the applications of forestry biomass resources had been treated seriously, and the relevant policies and regulations are continuously improved. In addition, appropriate technical personnel should be trained to overcome some bottlenecks. In China, these factors, such as a special population, resources, society and economic development, require combining China's national conditions with the development of forestry bioenergy. China should improve the institutional mechanisms and strengthen the scientific and technological innovation to find a path for the forestry biomass energy development with Chinese characteristics [46].

5.2. Prospects

Eventually, we make the following recommendations on how to make better use of forestry biomass resources:

1. Using third-party logistics to solve the availability of forestry biomass resources.
2. Improving the high-tech R&D of forestry biomass resources.
3. Improving the relevant standards for the development of the industrial forestry biomass resources.
4. Fully mobilizing the enthusiasm of enterprises to develop forestry biomass resources by policy tools and market mechanism.

Acknowledgments

This paper was supported by National Natural Science Foundation of China (Grant no. 71273090).

References

[1] Jie Yu. Informatics study on international development of bioenergy. Shanghai: Graduate University of Chinese Academy of Sciences; 2007; 1.
[2] Ning Guan. Bio-energy in the Western United States biomass utilization. International Wood Industry 2008;7(1):39–40.
[3] Jun He, Yi Yang. The reference of Finland and Sweden experience of biomass development. Macroecon Manag; 2014; 90–2.
[4] Tao Wang. The existing studies and prospect of forestry bio-energy in China. Beijing: Chinese Academy of Forestry; 2010; 1–6.
[5] Shiming Fei. The strategic thought to developing forestry bio-energy. J Sichuan For Sci Technol 2008;29(4):32–41.
[6] Xiaoping Gao, Yue Liu. Disposal of under forest fuel: from the forest fire prevention to biomass energy utilization. China Emergency Management 2010;12(1):25–7.
[7] Zhiwen Wu. Development of forestry biomass energy industry and cultivation of new economic growth point, Transformation of Economic Development and Innovation. Twelfth China Science and Technology Association Annual Meeting 2010;2(1):59–65.
[8] Zhu Gao, Jing Feng, Faxin Yu. The development tendency and existing studies of forestry biomass energy. J Anhui Agric Sci 2011;39(4):2126–8 (2137).
[9] Yuxiao Chen, Shengling Xiao, Qiang Wang. Research on the utilization of wood residues in forest area. Forest Eng 2007;23(6):1–5.
[10] Su Jin. Study on China's agricultural biomass energy industry development based on market mechanisms and government regulation. Heilongjiang: Northeast Forestry University; 2012; 5–8.
[11] Lei Huang. The research on forestry bio-energy utilization and its industry development in china. Beijing: Beijing Forestry University; 2008; 1–5.
[12] Energy Daily. Sino-Global Energy 2012;17(9):102–4.
[13] Tairong Sun. The energy exploitation and sustainable development of forestry biomass. Keji Zhifu Xiangdao 2013:330.
[14] Changzhu Li. Development and prospect of forestry biomass industry. Forest Ecol 2013:26–8.
[15] Jixin He, Ying Liu. Analysis of forestry biomass energy in the consumer market. J Jilin Radio TV Univ 2010:82–4.
[16] Fenglian Sun, Yapeng Wang, Weiwei Wang. Study of regional orientation, substitution potential and investigation and utilization countermeasure on forest biomass energy industry in China. Res Agric Modern 2010;31(3):325–9.
[17] Baoming Huo. The present situation and utilization of forestry biomass energy in Henan Province. J Henan Forest Sci Technol 2009;29(2):87–8.
[18] Heng Qiao, Jizhong Qi, Zhixin Wang. Overall idea for development and utilization of forestry biomass energy in Jilin Province. Jilin Forest Sci and Technol 2009;38(1):39–41.
[19] Yang Jiang. Study on the development strategy of biomass energy in state-owned forest region of Heilongjiang Province. Heilongjiang: Northeast Forestry University; 2010; 1–20.
[20] Chunxia Dou, Xuefeng Ji, Junyi Zhang. Analysis of biomass energy forest construction in Wulateqianqi. Forestry of Inner Mongolia; 2011; 14–5.
[21] Nuyun Li. Forestry biomass energy and climate change. The first global think-tank summit speeches 2009:190–2.
[22] Ying Zhang, Yan Chen. Analysis on competitive force of biomass energy industry in China – based on the theory of Porter's Diamond Model. J Yunnan Normal Univ 2011:1–6.
[23] Lan Zhang. Study on raw material supply and industrialization of forest biomass power in China. Beijing: Beijing Forestry University; 2010; 6–15.
[24] Fei Cai, Lan Zhang, Caihong Zhang. Potential of woody biomass energy and its availability in China. J Beijing Forest Univ (Social Sci) 2012;11(4):103–7.
[25] The Seventh National Forest Resources investigation. Chinese Forestry Network; 2013. See ⟨http://www.forestry.gov.cn//portal/main/s/3907/content-611030.html⟩.
[26] The Competitive Advantage of Ethanol Industry in China. Guangdong Price Information Network; 2008. See ⟨http://www.gdpi.gov.cn/scjjyjg/1378.jhtml⟩.
[27] Hu Teng, Ying Mu, Tiankui Yang. Advances in biodiesel research. Chin J Biotechnol 2010;26(7):892–902.
[28] Liuqin Chen. Discussion on biomass power generation in China. Decision-Mak Consult 2012:1–7.
[29] Lujing Sun. Alcohol fuel industry prospect. Chem Ind 2011;29(1):8–12.
[30] Qinghua Lu, Qing Zhu, Zuoyun He. The research on domestic and foreign biodiesel oil productive technology as well as its cost analysis. Pet Petrochem Today; 2011; 8–13.
[31] Mingming Zhang. The study of cost control based on H biomass power generation company. Henan: Henan University; 2013; 10–30.
[32] Yu Wang, Wei Kou, Yongcun Bian. Analysis of the straw resource status and straw biogas benefits. Environ Prot Circular Econ 2009:39–41.
[33] Hongmei Ding. The first forestry biomass energy development plan in China. Chinese Green Times 2013;6(3):1–2.
[34] Jianquan Li. Exploitation strengths and development opportunities of forestry biotransformation energy source in China. Forest Sci Technol 2010;35(1):52–8.
[35] Tian Zhang. Research on national laws and polices of development and utilization of biomass energy. Beijing: China University of Geosciences (Beijing); 2013; 21–9.
[36] The Eighth National Forest Resources investigation. Chinese Forestry Network; 2014. See ⟨http://www.forestry.gov.cn//portal/main/s/3161/content-659779.html⟩.
[37] Fenglin Wu, Jinying Wang, Jie Shen. Understanding of forestry biomass energy. Jilin Agriculture; 2011; 263.
[38] Zeling Zhang. Analysis of beer markets and competitive factors in different countries. Shandong: Ocean University of China; 2013; 14–8.
[39] Yan Ma. The design limitation of unit power of defibrator and the analysis on the measures of economizing energy. China Academic Conference: Wood and biomass resources utilization and security 2009;11(1):578–82.
[40] Feng Liu. The importance of accelerating the development of forestry biomass energy in China. Guide of Sci-tech; 2012; 231.
[41] Dan Wei, Xiaolong Han. Research on exploitation and utilization status and development policy of biomass energy in China. Special Zone Econ 2013:131–2.
[42] Xiangyi Cha. Discussion on the utilization status and problems of biomass in China. Agric Technol 2013:25.
[43] Yi Xie. Confusions in forestry biomass energy. China Energy News 2014;24(4):1–2.
[44] Ling Luo. Thoughts on the current raw material supply of forest biomass development status in China. Shandong For Sci Technol 2012:101–5.
[45] Xianfeng Liu, Xilin Shen. Research on the problems and countermeasures of developing biomass energy. Tian Fu New Idea; 2009; 56–9.
[46] Jian Hou, Peidong Zhang, Baorong Zhang. The development status of Chinese forestry biomass resource and the suggestion. Renew Energy Resour 2009;27(6):113–7.